

RECORDING TECHNIQUES

INTRODUCTION Although the process of writing binary information on magnetic tape may appear straightforward, considerable research has gone into both the development of the coded patterns used to represent "ones" and "zeros" and the decoding techniques. In writing information on tape, the digital information is supplied to recording circuitry for encoding in a form that is most compatible with the data and control equipments used in the primary system. Therefore, in selecting a particular magnetic recording coding method, compatibility with the control equipment in terms of ease of recording, cost, and data reliability must be considered.

In the following paragraphs, a number of coding techniques will be presented with their inherent advantages and disadvantages.

THE RECORDING PROCESS Magnetic tape is a natural storage medium for a two-state data system; it can be magnetized to indicate two states by field orientation (north-south or south-north). Magnetizing the tape is accomplished by switching current through the record head windings between different, pre-determined levels. In this manner, the tape area immediately in contact with the recording head gap is magnetized and holds a flux field pattern indicative of this process. The channel width is determined by the head gap width and the digital information is bounded by a pair of imaginary lines forming a magnetic field zone called a **cell**. In most cases, the deciphering of the recorded information is primarily dependent upon distinguishing the cell boundaries. Therefore, the transition from one cell to another and the corresponding magnetic state of adjacent cells determine the end of one bit and the start of the other.

Cell length is determined by tape speed, gap length, pole tip profile, fringe fields and the duration of the magnetizing current. In the space occupied by a cell, there can be areas of nonmagnetic fields. The nonmagnetic area may be deliberate or unintentional (poor tape quality), making cell boundaries difficult to determine. As a result, cell centers are used to decipher the written information. Hence, digital information is located on a positional or transitional basis, or both. For the purposes of this Application Memo, the two basic recording processes will be separated into two general categories, **Level**, and **Transitional**.

RECORDING TECHNIQUES (Refer to Figure 1)

A. LEVEL ENCODING

Pulse or Return to Zero (RZ) Encoding: A "one" is represented by a half-bit wide pulse and a "zero" is represented by a no pulse condition. To write a "one," the pulse-signal waveform momentarily changes from one d-c level to another and then returns to the original d-c level.

Since the tape can be magnetized in either state, pulse recording may have three signal levels. This, of course, requires the use of a null tape which has no magnetic field orientation prior to recording. This is accomplished by erasing the tape using a high frequency a-c waveform to randomly distribute the magnetic field. However, this is extremely awkward for most applications and finds little use today.

NRZ-L (Non-Return to Zero-Level): A "one" is represented by a particular level and a "zero" is represented by the opposite level.

NRZ-M (Non-Return to Zero-Mark): A "one" is represented by a change in level and a "zero" is represented by no change in level.

NRZ-S (Non-Return to Zero-Space): A "one" is represented by no change in level and a "zero" is represented by a change in level.

The advantages and disadvantages of the NRZ and RZ recording techniques are as follows:

NRZ & RZ — Advantages

- 1) These techniques obtain more bit density per unit length of tape than other recording techniques since the bit density is directly proportional to the flux changes per inch (fci).
- 2) The logic hardware to implement is usually a minimum.

NRZ & RZ — Disadvantages

- 1) The data recovery amplifier must have a DC response and show good phase linearity. Failure to do so creates distortion.
- 2) The pulse to pulse jitter and timing errors must not exceed $\pm$ one half-bit cell or the loss of data will occur.
- 3) Since data often consists of long strings of "ones" and "zeros," data synchronization is difficult.
- 4) Timing errors that exceed the half-bit cell require an increase in bit cell length which reduces the packing density.
- 5) The data recovery signal-to-noise ratio is decreased due to the larger bandwidth requirement.
- 6) These techniques require two recording tracks and thus reduce the total tape storage capability.
- 7) Tape skew becomes a problem due to the two track recording requirement.

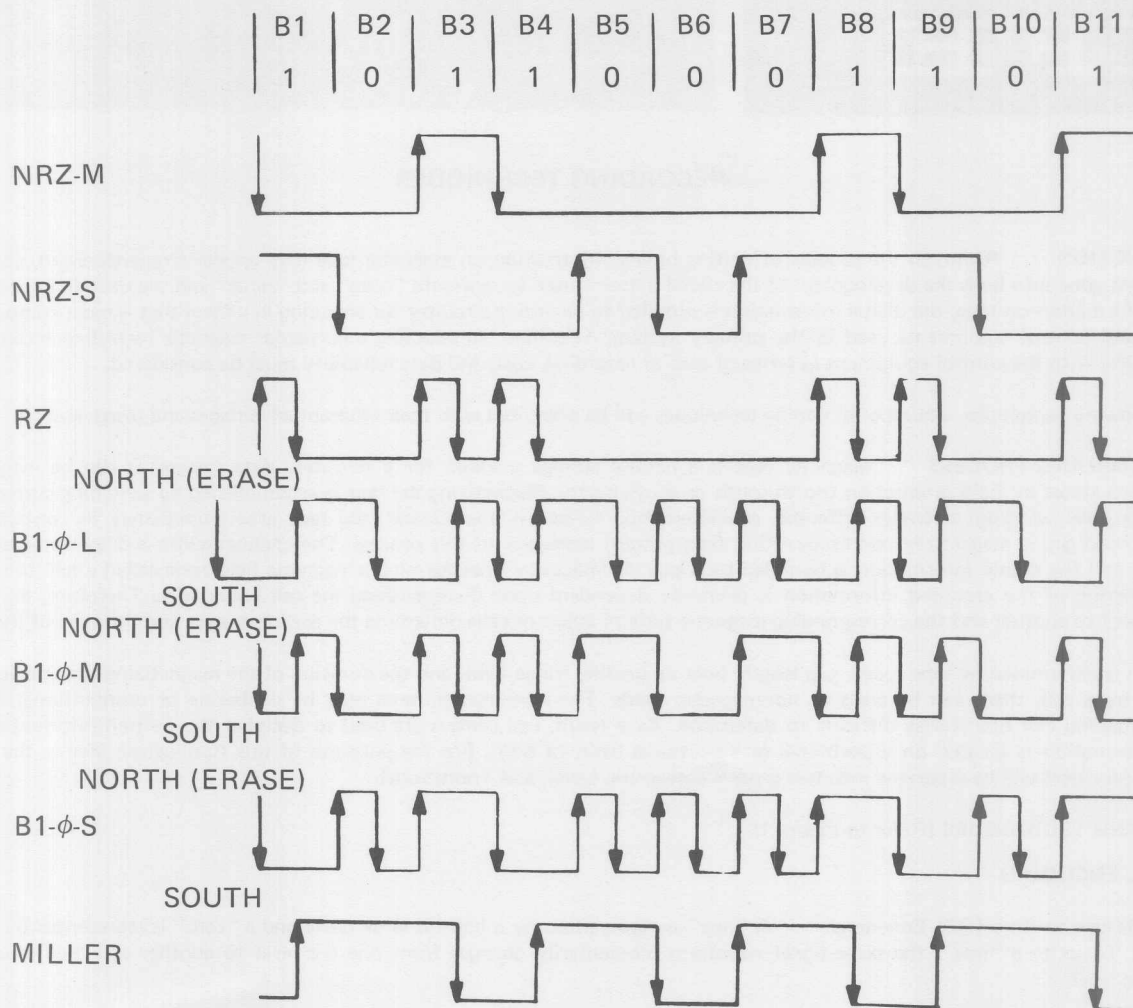


FIGURE 1
VARIOUS DATA ENCODED WAVE FORMS

B. TRANSITIONAL ENCODING

Bi-Phase-Level (or Split Phase, Manchester II + 180°) A "one" is represented by a flux transition toward the erase (magnetic north) direction. A "zero" is represented by a flux transition away from the erase level in a magnetic south direction. Additional phase flux transitions are written at midpoints between bit flux transitions to establish the proper polarity for the succeeding bits.

Bi-Phase-Mark (or Manchester I) A flux transition occurs at the beginning of every bit time. An additional flux transition occurs at the midpoint of the bit time if the bit to be written is a "one." There is no flux transition at the midpoint if the bit to be written is a "zero." The direction of a flux transition has no meaning.

Bi-Phase-Space The Bi-Phase-Space method is the converse of the Bi-Phase-Mark. A flux transition occurs at the beginning of every bit time. An additional flux change is made at the midpoint of the bit time if the data to be written is a "zero."

The advantages and disadvantages of the Bi-Phase-Mark and Bi-Phase-Level recording techniques are as follows:

Bi-Phase-Encoding—Advantages Phase encoding provides higher bit density and insures that a flux reversal exists for each bit cell to provide self-clocking on a single track. This simplifies the electronics and allows read-after-write capabilities with acceptable crosstalk characteristics.

Phase encoding reduces the effect of pulse crowding since a transition occurs for each bit and the requirement for DC coupling (extending the frequency bandwidth to 0 Hz) is eliminated.

Pulse-to-pulse jitter becomes negligible because there is a transition for each clock period regardless of the data content.

Data recovery problems caused by tape skew between the "clock track" and the "data track" are nonexistent.

Bi-Phase-Encoding—Disadvantages Because there is at least one flux change per bit cell, more flux changes are required to write the data. Thus, for cassette tape (.5 mil), pulse crowding occurs at bit densities above 600 BPI.

The data recovery amplifiers must be designed to account for phase shift at both the low frequency and high frequency to minimize bit shifting due to phase error.

Miller Code A flux transition in either magnetic direction at the mid-point of a bit cell represents a "one." A flux transition in either magnetic direction at the end of a zero's bit cell represents a "zero" followed by a "zero."

Miller Code—Disadvantages

- 1) The Miller Code does not have any of the disadvantages seen in the NRZ and RZ or Phase Encoding methods, other than the phasing of the clock requires the presence of a "101" sequence in the frame or word sync to establish the proper clock and data phase in the decoder.
- 2) However, the Miller Code is somewhat more complicated to implement logic-wise and is more difficult for synchronizing data for transmission purposes.

Miller Code—Advantages

- 1) This code contains its own clock by providing at least one transition every other bit.
- 2) The data recovery amplifiers do not need to have a response to DC.
- 3) Provides higher bit density recording along with self-clocking on a single track.
- 4) Pulse-to-pulse jitter becomes less important because there is a transition for each clock period regardless of the data content.
- 5) Data recovery problems caused by tape skew between the "clock track" and the "data track" are nonexistent.

DATA FORMATTING TO BE USED WITH MFE TAPE TRANSPORTS Because of the high ratio of disadvantages to advantages for the NRZ and RZ recording techniques, as well as ease of implementation, MFE recommends the following recording techniques for use with their tape transports.

Bi-Phase-Mark
Bi-Phase-Level
Bi-Phase-Clock

Assembled printed circuit boards for any of these recording techniques are available for purchase from Computer Access Systems. These printed circuit boards plug directly into the interface connector to provide the necessary data formatting, writing, and reading.

Bi-Phase-Mark (refer to Figure 2) The Bi-Phase-Mark schematic contains the necessary logic to receive the data from the user's register, format the data properly, write the data on tape, recover the data, and shift it back out to the user along with a timing clock. The user must initiate all motion commands and consider the start/stop times and distances to properly utilize the transport (refer to the "Model 250 Operation and Interface Manual" for requirements).

Referring to Figure 3, note that a flux change is always made at the start of each data bit cell (arbitrarily called a sync bit) and a flux change is made in the middle of the cell only when a data bit "one" is to be written. No flux change occurs for a "zero."

Note from this timing diagram that there is a 50 msec delay between the initial tape motion command, FORWARD GO, and the actual beginning of the writing. This delay of course is necessary to insure that tape is up to speed before writing, thus preserving correct bit density. The read logic employs a one-shot to obtain the data bit window or gate. The adjustment of the data recovery one-shot time period is the same for the Bi-Phase-Level and the Bi-Phase-Mark recording technique. The calculations are given in the next section.

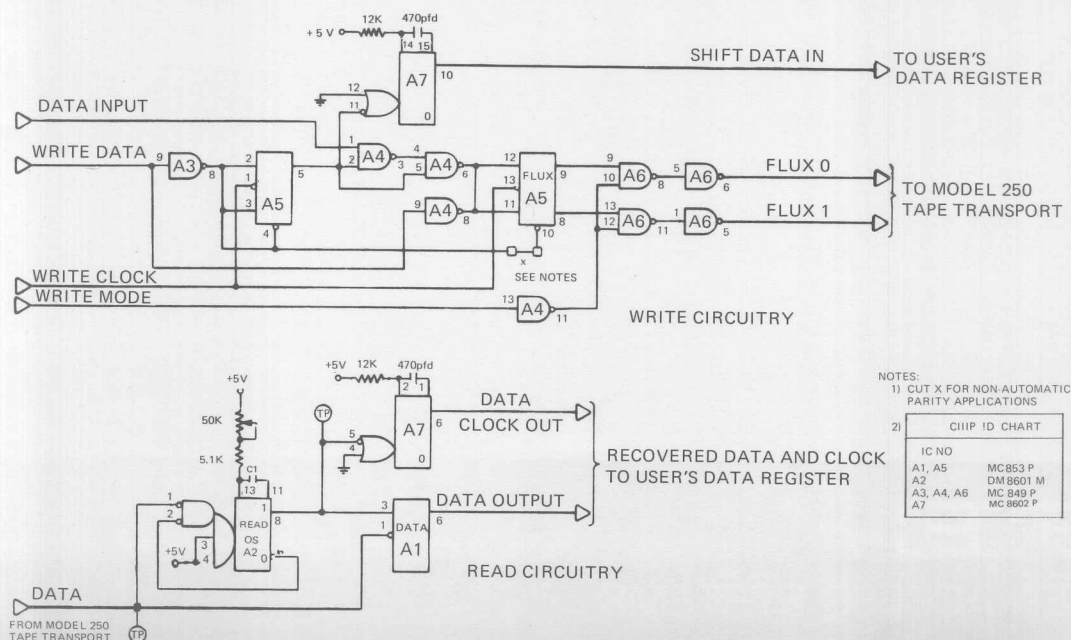


Figure 2.
BiPhase Mark Read/Write Schematic

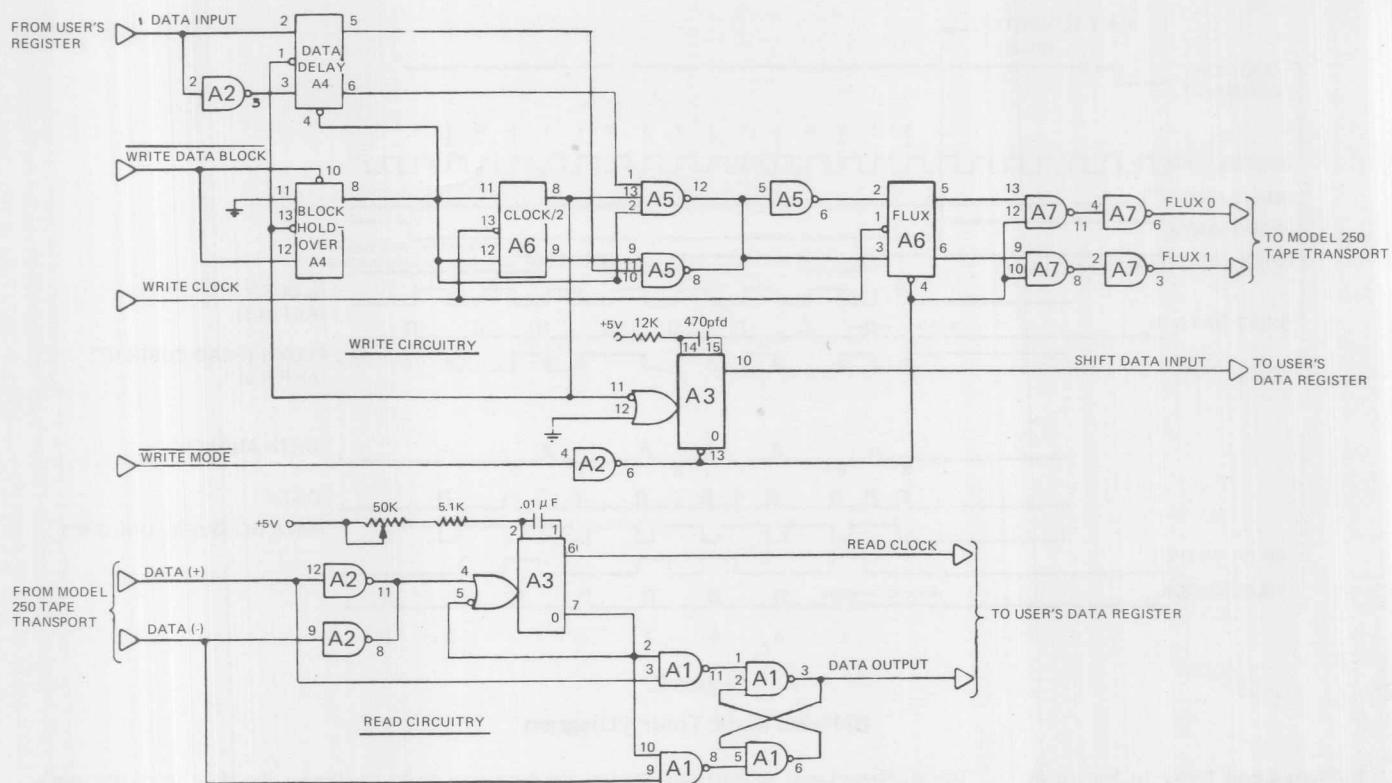


Figure 4.
Bi-Phase Level Read/Write Schematic

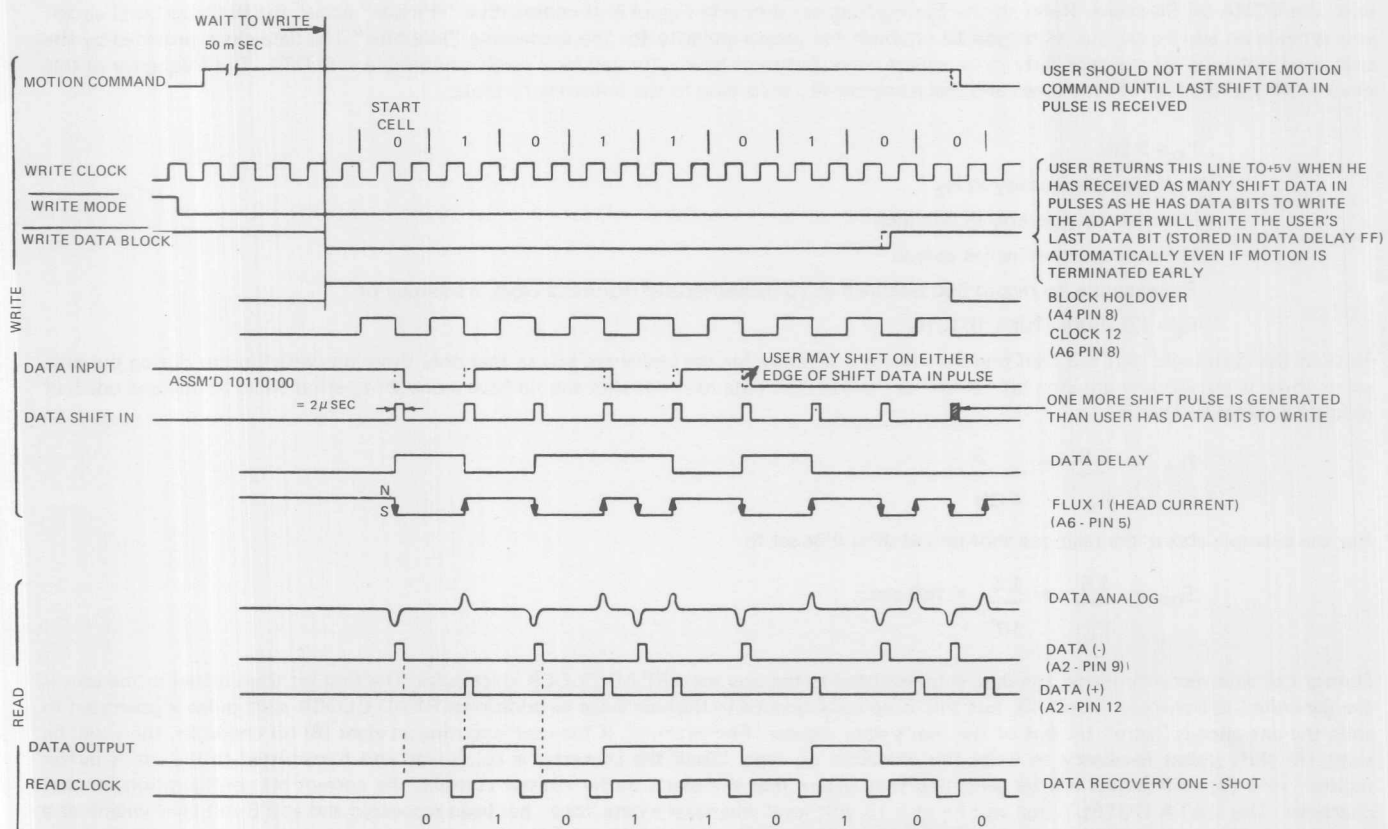


Figure 5
Bi-Phase Level Timing Diagram

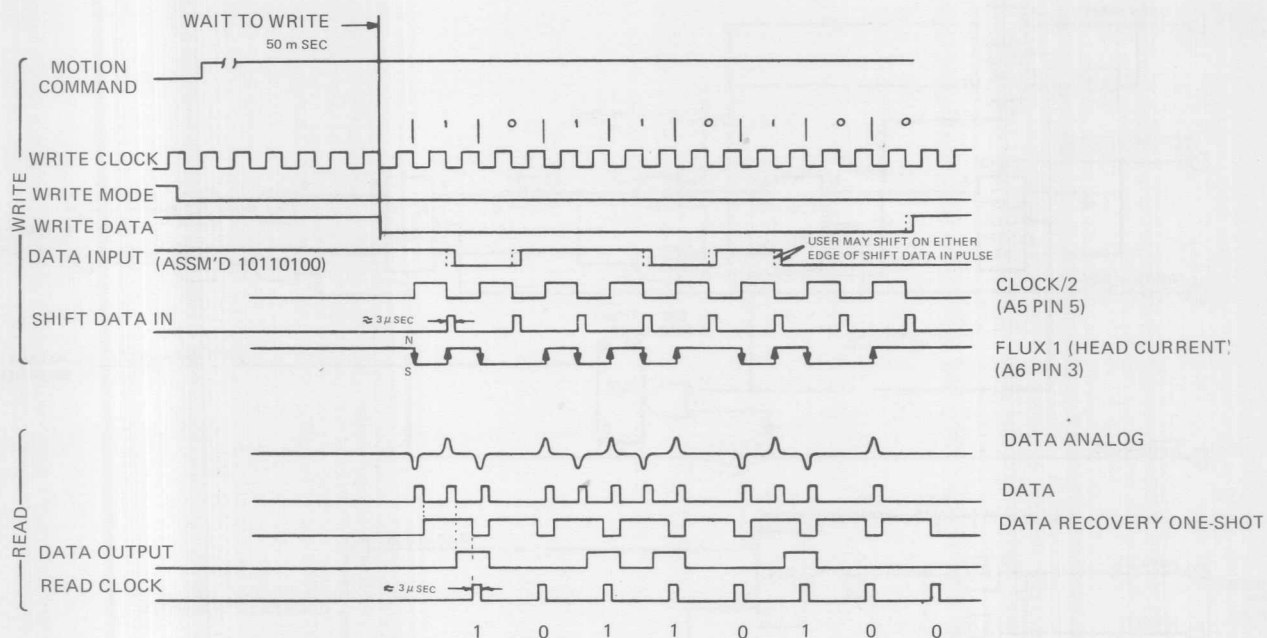


Figure 3.

Bi-Phase Mark Timing Diagram

Bi-Phase-Level (refer to Figure 4) The Bi-Phase-Level schematic contains the necessary logic to receive the data from the user's register, format the data into a Bi-Phase-Level format, write the data on tape, recover the data, and shift it back to the user.

The user must initiate all motion commands and consider the start/stop times and distances to properly utilize the C-DRIVE. Since the Bi-Phase-Level recording technique does not utilize a sync bit (a flux transition occurring at the beginning of each data bit cell), an extraneous "zero" bit is generated prior to the first data bit transmitted by the user. This compensates for the condition when the first bit of the data block is a "one," and ensures that current is passed through the write head in the magnetic north direction in accordance with the ECMA-34 Standard. Refer to the Timing Diagram shown in Figure 5. If consecutive "like bits" occur, the Bi-Phase-Level circuit will provide an additional flux transition to establish the proper polarity for the succeeding "like bits." The data clock provided by the user need not be a 50 per cent duty cycle square wave, but must have saturated logic levels compatible with DTL. The frequency of this clock is only a function of tape speed and recording density according to the following formula:

$$F_c = 2 DN$$

$$F_c = \text{clock frequency in Hz}$$

$$D = \text{recording density in bits/inch}$$

$$N = \text{tape speed in inches/second}$$

For example, to record 500 bits/inch at 10 inches/second requires a clock frequency of:

$$F_c = (2) (500) (10) = 10 \text{ K Hz}$$

Note in the read logic that the read one-shot forms a window for the unwanted bits so that only those bits which occur during the time when there is no window are data bit "zeros" or "ones." The data read one-shot should have a one-shot period equal to one and one-half data clock periods. That is

$$T_{os} = \frac{1.5}{F_c} = \frac{3}{4 DN}$$

For the example above, the read one-shot period should be set to

$$T_{os} = \frac{1.5}{F_c} = \frac{1.5}{10^4} = 150 \text{ usec.}$$

During the data recovery mode, the data is transmitted to the user via a READ CLOCK shift pulse. The first bit transmitted to the user is the generated extraneous "zero" bit, but this is no consequence to the user since an additional READ CLOCK shift pulse is generated to shift the extraneous "zero" bit out of the user's data register. For example, if the user is writing an eight (8) bit character, there will be eight (8) shift pulses necessary to write the character on tape. When the character is being read and transmitted to the user's buffer register, nine (9) shift pulses will be generated that ensure that the user's buffer register contains the correct bit configuration for that character. The DATA OUTPUT line will be at a +5 volt level whenever a data "one" has been recovered and at a 0 volt level whenever a data "zero" bit has been recovered. A +5 volt pulse will appear on the READ CLOCK line whenever a data bit has been recovered from the tape. The user may use either edge of this pulse to shift the recovered data which is present on the DATA OUTPUT line at that time into the user's data buffer register.

Bi-Phase—Clock Normally, when using an external clock to record data on the Model 250 Tape Transport, the user must wait at least 50 milliseconds after starting the tape in motion before writing can begin. This is to preserve the bit density by ensuring the tape is up to speed. With the Bi-Phase—Clock method, a Bi-Phase recording technique is used to record data using the prerecorded tape speed control clock track as the data clock. By using this technique, the user need not wait the required 50 milliseconds before writing may commence. Thus, when writing incrementally: 1) data can be recorded faster, 2) more data characters can be recorded per unit length of tape, 3) data is recorded independent of the tape speed, and 4) interfacing of different baud rates is accomplished by simply changing tape speed. Any number of clocks could be chosen to comprise the bit cell. Obviously, the more clocks that are used for each bit cell, the lower the recording density and the higher the reliability. This technique is highly recommended when the Model 250 is used to write incrementally by character at high increment rates. Because this recording technique is so unique and powerful, its implementation and use is discussed in a separate Application Note. For more detail, refer to the Model 250 Interface specification and the above mentioned Application Note.

INTER-RECORD-GAP The Inter-Record-Gap (IRG) is defined as the distance between two successive data blocks. To be compatible with the ECMA and ANSI specifications, the IRG shall be a minimum length of 0.7 inches. This gap constitutes the distance allotted for the starting and stopping of the Model 250 Transport. Whenever continuous blocks of data are written on tape, the IRG must be written to enable the transport to start and stop between records if required during the read operation. A one-shot can be implemented to provide the required minimum gap length. During the read mode, the IRG one-shot can be synchronized to indicate when an IRG occurs. By using the prerecorded clock track, a gap detector can be implemented by using the clocks to count and using the data track to reset the counter. Thus when data is present, the counter will be continually reset. When there is no data, the counter will count to a pre-determined count (say 16) and trigger an IRG circuit indicating that data is absent and the tape is at an IRG.

PREAMBLE/POSTAMBLE MFE recommends the use of the Preamble/Postamble codes when recording large blocks of data. The advantage is that when reading a block of data, the user detects the preamble code and is assured that the information following is indeed data. This eliminates the danger of detecting externally generated noise and recognizing it as data. The Postamble detects the end of the data block. The disadvantages are 1) the user must provide the logic to write and interpret the code and 2) if writing short data blocks, such as single eight (8) bit characters, the tape space allocated to the codes becomes significant and poor utilization of the tape real estate results.

Preamble The ECMA-34 Standard requires that immediately preceding the data in each block, the Preamble "10101010" shall be written. When reading in the forward direction, the first flux transition shall be a "zero" transition.

Postamble Immediately following data in each block, the Postamble "10101010" shall be written. When reading in the forward direction, the first flux transition shall be a ZERO transition. For a complete discussion of the preamble and postamble technique, the reader should consult the ECMA-34 specification.

CONCLUSION The first generation of cassette tape transports used NRZ and RZ methods of recording, but because of the many disadvantages, other methods were investigated. MFE researched the Bi-Phase-Mark and Bi-Phase-Level recording techniques and found that the reliability of cassette tape recording was improved greatly. To make it easier to write and read data using the Model 250 Cassette Tape Transport, assembled encode/decode boards can be purchased from Computer Access Systems using either the Bi-Phase-Mark, Bi-Phase-Level, or Bi-Phase-Clock recording techniques. Since the Model 250 utilizes a prerecorded clock track, the Bi-Phase-Clock recording technique is a very powerful technique when data is to be recorded incrementally by character or the data baud rate is to be variable.

MFE

COMPUTER ACCESS SYSTEMS

KEEWAYDIN DRIVE • SALEM, NEW HAMPSHIRE 03079
TEL. 603-893-1921 • TWX 710-366-1887 • TELEX 94-7477

AN64-10M